Goddard Latent Heating Retrieval Algorithm

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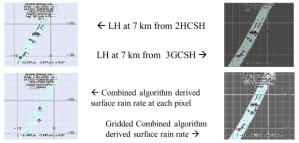
Introduction

Rainfall production is a fundamental process within the Earth's hydrological cycle because it represents both a principal forcing term in surface water budgets, and its energetics corollary, latent heating, is the principal source of atmospheric diabatic heating. Latent heat release itself is a consequence of phase changes between the vapor, liquid, and frozen states of water. The properties of the vertical distribution of latent heat release modulate large-scale meridional and zonal circulations within the Tropics - as well as modify the energetic efficiencies of mid-latitude weather systems. Both TRMM and GPM measurements have been providing an accurate four-dimensional account of rainfall over the global Tropics and mid-latitudes: information that can be used to estimate the space-time structure of latent heating.

The Goddard Convective-Stratiform Heating (CSH) algorithm has been used to retrieve latent heating (LH) associated with clouds and cloud systems in support of the TRMM and GPM missions. The CSH algorithm requires the use of a cloud-resolving model (CRM) to simulate LH profiles to build look-up tables (LUTs). However, the current LUTs in the CSH algorithm are not suitable for retrieving LH profiles at high latitudes or winter conditions that are needed for GPM. The NASA Unified-Weather Research and Forecasting (NU-WRF) model is used to simulate three eastern continental US (CONUS) synoptic winter and three western coastal/offshore events to build LUTs suitable for higher latitude/cold season precipitation systems.

CSH Standard LH Products

	Spatial Scale	Temporal Scale	Input Data	Name
Gridded	0.25 x 0.25 degree 80 vertical layers	Monthly	CSH-Combined	3HCSH
Orbital	Pixel 80 vertical layers	Instantaneous	CSH-Combined	2HCSH
Gridded Orbital	0.25 x 0.25 degree 80 vertical layers	Instantaneous Time Stamps on each grid	CSH-Combined	3GCSH

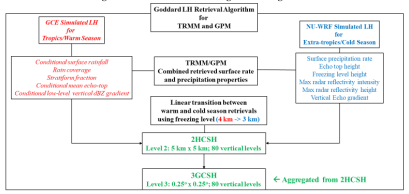


Major Characteristics of the CSH and SLH Algorithm

	SLH	CSH
Key References	Shige *et al.* (2003, 2007, 2008, 2009)	Tao *et al.* (1993, 2000, 2001, 2010, 2019), Lang and Tao (2018)
Cases	Tropics: TOGA COARE Winter: 6 oceanic events	Tropics: 10 field campaigns (land and ocean) Winter: 6 events (land and ocean)
Input	PR/DPR	Combined GMI/DPR
Products	LH, Q1R, Q_2	Tropics: LH, QR, Q_2 and , Eddy Heating and Moistening *High latitudes: LH only*
Look-up Tables	No horizontal eddy Based on CRM domain and **time (5min)** averaged. Consistent with surface rainfall	Combined horizontal and vertical eddy Sampling 4 km (GCE) and 3 km (NU-WRF) km model

Convective and Stratiform Separation method: SLH based on GCE method and CSH based on DPR method

Schematic diagram of Goddard latent heating retrieval algorithm for GPM/TRMM



Goddard Latent Heating Algorithm and Its Improvement

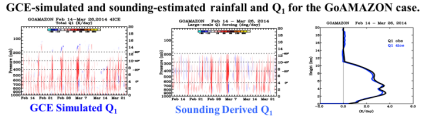
Improved CSH look-up tables for the **Tropics**

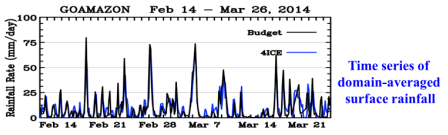
Field Campaign	Geographic Location	Dates	Modeling Days	Reference(s)
ARM SGP 97	Land (Southern Great Plains)	June - July, 1997	29	Tao et al. (2004); Zeng et al. (2009)
ARM SGP 02		May - June, 2002	20	Zeng et al. (2007, 2009)
SCSMEX/NESA	Ocean (South China Sea)	May – June, 1998	45	Tao et al. (2003b), Zeng et al. (2008)
TOGA-COARE	Ocean (Equatorial West Pacific)	November, 1992 – February, 1993	61	Das et al. (1999); Johnson et al. (2002); Zeng et al. (2009)
GATE	Ocean (Tropical Atlantic)	August – September, 1974	20	Tao et al. (2004); Zeng et al. (2009)
KWAJEX	Ocean (Marshall Islands)	July – September, 1999	52	Zeng et al. (2008)
TWP ICE	Ocean (Darwin, Australian)	January – February, 2006	24	Zeng et al. (2013)
MC3E	Land (Southern Great Plains)	April – March, 2011	33	Zeng et al. (2017)
DYNAMO	Ocean (Equatorial Indian Ocean)	November – December, 2011	31	Li et al. (2018)
GoAMAZON	Land (Amazon Basin)	February – March, 2014	40	Lang and Tao (2018)

In all, the GCE model CSH database has more than ***three hundred fifty-five days*** (122 days **continental cases** and 233 days **oceanic cases**) of model integration.

Lang, S. E., and W.-K. Tao, 2018: The Next-generation Goddard Convective-Stratiform Heating Algorithm: New Tropical and Warm Season Retrievals for GPM. *J. Climate*, V31, No 5, doi: 10.1175/JCLI-D-17-0224.1.

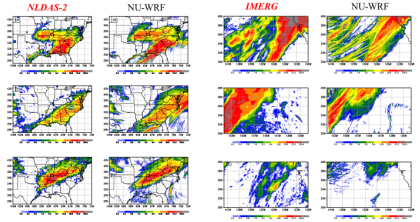
GCE-simulated and sounding-estimated rainfall and Q_1 for the GoAMAZON case.



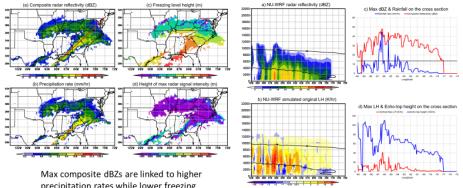


Time series of domain-averaged surface rainfall

NU-WRF simulated rainfall for 3 US east coast and 3 CalWater cases. NLDAS-2 and IMERG are used for comparison.



Tao, W.-K., T. Iguchi, and S. E. Lang, 2019: Expanding the Goddard CSH Algorithm for GPM: New Extra-tropical Retrievals. *J. Applied Meteor. Climatol.*, **58**, 921-946, doi: 10.1175/JAMC-D-18-0215.1



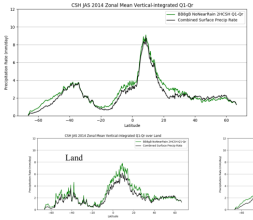
Max composite dBZs are linked to higher precipitation rates while lower freezing level heights are linked with lower Max dBZ heights.

A close relationship between dBZ and heating occurs beneath the freezing level

Large surface precipitation rates have high composite dBZs; Strong LH occurs with high echo tops, but high echo tops do not always imply strong LH

Goddard Latent Heating Algorithm Retrieved Latent Heating Structure

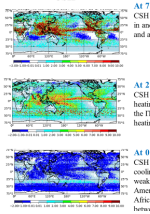
CSH retrieved zonal mean vertically-integrated Q_1-Q_R ***for July, August and September 2014***



Goddard LH algorithm **"equivalent surface rain rate" is** stronger (or higher) than the **Combined** rain rate over land.

But it is in agreement with the Combined surface rain rates over the ITCZ region over ocean

CSH

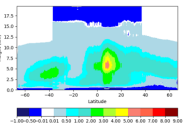


At 7 km level: CSH has strong heating in and around the ITCZ and also over land

At 2 km level: CSH also has strong heating in and around the ITCZ but has weak heating over land

At 0.25 km level: CSH has overall cooling. But it has weak heating in S. America, Australia, S. Africa, and the region between 25 and 35°S

Mean Zonal Heating for July-Aug-Sept 2014



Level of maximum heating is at 5.5 km and occurs in the ITCZ. More low-middle heating in S. Hemisphere than N. Hemisphere. Low level cooling is stronger in N. Hemisphere than S. Hemisphere.

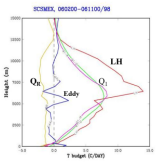
Vertically-integrated LH (equivalent surface rain) vs Combined retrieved surface rain

$$Q_1 - Q_R \approx \bar{\pi}\left[-\frac{1}{\bar{\rho}}\frac{\partial \overline{\rho w'\theta'}}{\partial z} - \bar{V}'\bullet\nabla\theta'\right] + \frac{L_c}{C_p}(c-e) + \frac{L_f}{C_p}(f-m) + \frac{L_s}{C_p}(d-s)$$

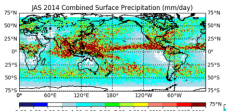
Q1R= Q_1-Q_R — **Eddy Transport** — **LH: Latent Heat - phase change of water**

$$\frac{1}{g}\int_{Ltz}\int_{P_{top}}^{P_{base}}(Q_1 - Q_R)\Delta p\Delta x - S_h = LP_h$$

There is an assumption for the above equation: Yanai *et al.* (1973) stated: ***"we consider an ensemble of cumulus clouds, which is embedded in a tropical large-scale motion system, then we imagine a horizontal area that is large enough to contain the ensemble of clouds, but small enough to be regarded as a fraction of the large-scale system (a GCM Grid Box)"***

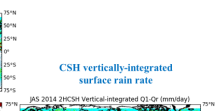


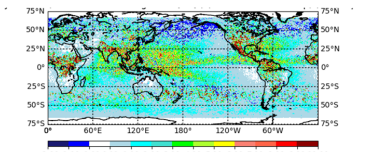
Very similar pattern (distribution) between Combined and vertically-integrated Q_1-Q_R (equivalent" surface rain rate) at **0.25° x 0.25° resolution**



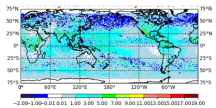
Combined retrieved mean surface rain rate

CSH vertically-integrated surface rain rate

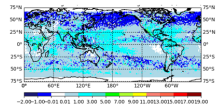




Differencing the mean surface rainfall rate from the Combined algorithm and from the mean column-integrated CSH cloud diabatic heating rates ($Q_1 - Q_R$) for the 3-month period at **0.25° x 0.25° resolution.** ***The difference (plot) can be used as a flag for Goddard Latent Heating Retrieval!***



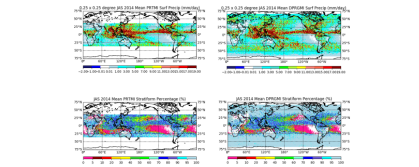
Differencing the mean surface rainfall rate from the Combined algorithm and from the mean column-integrated CSH cloud diabatic heating rates ($Q_1 - Q_R$) for the 3-month period at **0.5° x 0.5° resolution (left) and 1.0° x 1.0° resolution (bottom)**

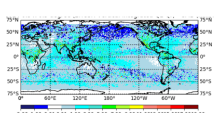


The difference between the Combined algorithm and the mean column-integrated cloud diabatic heating rate from CSH depends on the horizontal resolution.

Larger difference at higher horizontal resolution.

PMM Precipitation - July –August-September 2014





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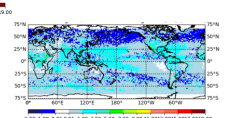

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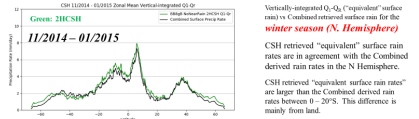

Vertically-integrated Q_1-Q_R ("equivalent" surface rain) vs Combined retrieved surface rain for the ***winter season (N. Hemisphere)***

CSH retrieved "equivalent" surface rain rates are in agreement with the Combined derived rain rates in the N Hemisphere.

CSH retrieved "equivalent surface rain rates" are larger than the Combined derived rain rates between 0 – 20°S. This difference is mainly from land.

SUMMARY & FUTURE WORK

2HCSH retrieved Q_1-Q_R are in agreement with the combined surface rain rates for both TRMM and GPM (especially at and near the ITCZ)

2HCSH results are averaged to produce 3GCSH products (consistent with combined derived rain rates).

CSH vertically-integrated surface rain rate and its difference with combined derived surface rain rate can be used for flags

Will continue to examining the positive bias in the vertically-integrated L2 LH in the sub-tropics (large heating over land regions)

Will use 3D GCE modeled LH for the next version of the Goddard LH algorithm look-up tables

Will use NU-WRF modeled LH for more cold season and high latitude cases (C3VP, IFlooodS, LPVEx, NAMMA ….)